2012 International Conference on Future Electrical Power and Energy Systems

On-Line Monitoring Technology for Moisture Content of Sulfur Hexafluoride Circuit Breakers

Xu Yuanzhe¹, Zheng Shengpeng², Jin Guangri³

¹Electrical Engineering College, Northeast Dianli University, Jilin, China
²School of Automation Engineering, Northeast Dianli University, Jilin, China
³PetroChina Jilin Petrochemical Company Calcium Carbide Factory, Jilin, China

Abstract

As the moisture content over standard in sulfur hexafluoride (SF6) circuit breakers will menace operation of apparatus and grid. Based on the infrared spectrum absorption, a system using absorption type optic fiber for moisture content detection was studied. The system used semiconductor laser as light source and used harmonic measurement to improve the detection sensitivity. The moisture content has a linear relationship with the output signal. The experimental results show that method of spectrum absorption can not only accurately detect moisture content but also fit for on-line detection.

© 2012 Published by Elsevier Ltd. Selection and/or peer-review under responsibility of Hainan University.

Keywords: sulfur hexafluoride(SF6); on-line monitoring; moisture content; spectrum absorption

1. Introduction

SF6 gas is by far the best insulation and arc media, widely used in SF6 equipment[1]. The results show that the greatest danger in SF6 gas impurities is water. SF6 gas which has too high moisture content will produce toxic decomposition products which lead to machinery failure and surface flashover voltage sharply, and endanger the safe operation of equipment[2], Table 1 is the provisions of national standard GB/T8905-1996 " SF6 gas detection equipment and gas management guidelines" on the water content of SF6 equipment at twenty degrees centigrade.

<table>
<thead>
<tr>
<th>Compartment</th>
<th>There are decomposition of the compartment (μL/L)</th>
<th>No arc decomposition of the compartment (μL/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Allowed value of transfer</td>
<td>≤150</td>
<td>≤500</td>
</tr>
<tr>
<td>Allowed value of operation</td>
<td>≤300</td>
<td>≤1000</td>
</tr>
</tbody>
</table>

Table 1. Moisture content requirements of national standards
The measurement of moisture content in SF₆ equipment is susceptible to outside interference, so the requirements to precision, sensitivity and stability are relatively high. Currently, there exist traditional methods for the detection of water content in SF₆ gas are weight method, electrolysis method, dew point method, RC method[3]. These traditional methods are off-line testing of preventive methods which could not monitor the operation of switching equipment situation real-time.

In this paper, spectrum absorption method was used in detection of water content in SF₆ gas. The system using spectrum absorption method had advantages as follows: 1. The system is simple and reliable. It is fit for long-term measurement and online real-time monitoring; 2. It is user-friendly, easy to form a network of direct control by PC and without complicated operation; 3. The system has high sensitivity of the gas identification capability, short response time and affected by little interference. The method will improve the switching equipment, real-time detection of water content, and improve the safety of electrical equipment and switch operation has far-reaching significance.

2. Detection Principle

The monochromatic light whose beam intensity is I₀ and wavelength is λ irradiates the gas chamber. If the gas absorption lines in the spectral range of light source, the decay occurs when light passes through the chamber. According to Beer-Lambert law[4], the output light intensity I(λ) has a relationship with the input light intensity I₀(λ) as follows,

\[ I(\lambda) = I_0(\lambda) \exp[-\alpha(\lambda)LC] \]  

(1)

Where \( \alpha(\lambda) \) is absorption coefficient of the gas at a certain frequency and unit length; L is the effective length of light and gas; C is gas concentrations.

According to the equation (1), C can be expressed as,

\[ C = \frac{1}{\alpha(\lambda)L} \ln \frac{I_0(\lambda)}{I(\lambda)} \]  

(2)

Where if L and \( \alpha(\lambda) \) is known, by detecting the I(λ) and I₀(λ) can measure the moisture content.

In addition, the gas absorption rate of light energy is a function of wave frequency, by modulating the frequency of light, the modulation of absorption coefficient can be achieved. If the source spectral distribution of the bandwidth is much smaller than the gas absorption line bandwidth, the light source through the injection current of sinusoidal modulation, frequency and output light intensity will also be a corresponding modulation.

\[ \nu = \nu_0 + \nu_m \sin(\omega t) \]  

(3)

\[ I' = I_0[1 + m \sin(\omega t)] \]  

(4)

Where \( \nu_0 \) is the center frequency of light without modulation, \( \nu_m \) is the frequency of modulation amplitude, m is optical modulation index, \( \omega = 2\pi f \) is the current modulation frequency. In the near infrared, gas absorption coefficient is very small so the \( \alpha(\lambda)LC \leq 1 \). Light intensity modulation amplitude is small, \( m \leq 1 \). When output center wavelength of the light source is accurately locked in the gas absorption peak:

\[ I = I_0[1 + m \sin(\omega t) - \frac{\alpha_0LC}{1 + x^2 \sin(\omega t)}] \]  

(5)
Where $\alpha_0$ is the center absorption coefficient of pure gases in the absorption line. The equation (5) can be expanded as Fourier series, and its first harmonic $f$ and the second harmonic $2f$ of the coefficients are

$$I_f = mI_0$$

$$I_{2f} = -k\alpha_0 LCI_0$$

First harmonic component has no relationship with gas concentration. Second harmonic component has a linear relationship with the gas concentration, gas concentration information can be obtained by detecting the second harmonic signal[5].

3. Detection System Design

3.1 System Structure

System structure is shown as Figure 1. Light through optical fibers into the air chamber, interact with moisture, and then transmit to the PIN photodetector in which the optical signals are transformed into electrical signals. Detector output signals are improved by filter circuit and lock-in amplifier circuit to eliminate the dark current of detector. The final signals are converted into digital signals and given into the computer for processing and display.

![Figure 1. System diagram](image)

3.2 Laser and Detector

In Figure 2, the standard feature of micro-water absorption lines are in the infrared (2.6μm-2.8μm) of the vibration spectrum. This band is far beyond the quartz optical fiber transmission window (1μm-1.7μm) which is high attenuation in the quartz fiber area, and is not widely used in optical fiber gas measurement. Therefore, the harmonic spectrum in the quartz optical fiber transmission window is usually used for detection. Moisture in the near 1.365μm has a strong absorption peak wavelength and the attenuation of fiber is very low. Detection sensitivity of the system would be quite high[6]. Therefore the system chooses 1.365μm as the absorption peak, and selects the corresponding semiconductor laser as light source and InGaAs PIN photodetector as detector.

Semiconductor laser uses semiconductor material as the working substance. Compared to solid-state laser and gas laser, it has advantages of small, light weight, easy pump and modulation.

InGaAs PIN photodetector has the main advantages of high quantum efficiency, low noise, fast response, linear range, small size and ease to use.
3.3 Chamber Design

Chamber includes the input and output lenses. The lens is small gradient index lens which can well match the fiber. Transmission fiber and the lens can be directly welding together to improve the stability and efficiency of the coupling. In Figure 3, light emitted from the optical fibers, through the lens into a parallel input, coupled to the fiber by the output lens.

The length of the chamber has a great influence on measurement sensitivity. As the chamber length increases, the light is absorbed more absolutely, thereby enhancing the detection sensitivity. Beer-Lambert law is established when the material ability to absorb molecules from the impact of neighboring molecules around it. When the moisture content is large, the interaction between molecules can not be ignored, at this time Beer-Lambert law is not established \(^7\).

Select the length of chamber 50cm, not only to ensure adequate absorption process, but also to maintain the accuracy of measurement.

4. Experiment

At first, cleared the gas chamber with pure nitrogen and injected SF\(_6\) gas into the gas chamber. Oscilloscope connected to the output of lock-in amplifier to detect the second harmonic voltage signal. For different moisture content, the corresponding second harmonic signals were detected. The experimental results were shown in Table 2.

<table>
<thead>
<tr>
<th>No.</th>
<th>moisture content(ppm)</th>
<th>second harmonic signal(mV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>100</td>
<td>5.2</td>
</tr>
<tr>
<td>3</td>
<td>300</td>
<td>14.1</td>
</tr>
<tr>
<td>4</td>
<td>500</td>
<td>22.7</td>
</tr>
<tr>
<td>5</td>
<td>1000</td>
<td>42.9</td>
</tr>
<tr>
<td>6</td>
<td>2000</td>
<td>82.2</td>
</tr>
<tr>
<td>7</td>
<td>2500</td>
<td>98.1</td>
</tr>
<tr>
<td>8</td>
<td>4500</td>
<td>170</td>
</tr>
<tr>
<td>9</td>
<td>6500</td>
<td>213</td>
</tr>
<tr>
<td>10</td>
<td>8500</td>
<td>268</td>
</tr>
<tr>
<td>11</td>
<td>10000</td>
<td>301</td>
</tr>
</tbody>
</table>
According to the experimental data, draw curve shown in Figure 4. In Figure 4, moisture content has a linear relationship with the second harmonic output. Second harmonic output voltage increases as the moisture content increases linearly. The results are basically consistent with the theoretical analysis. Several tests under the same conditions show stability and reproducibility of water vapor absorption are good.

Figure 4. Experimental curve of moisture content

5. Conclusion

Theory and experiments show that spectrum absorption is fit for the detection of moisture content in the SF₆ circuit breakers. With advantages of convenience, high sensitivity and resistance to the electromagnetic interference, the method of spectrum absorption can detect the moisture content on-line.

References


